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1992-1993 WINTER PRECIPITATION

IN SOUTHWEST ARIZONA

NATHANIEL GUTTMAN

NATIONAL CLIMATIC DATA CENTER

JUNG JIN LEE

SOONGSIL UNIVERSITY

JAMES WALLIS

IBM WATSON RESEARCH CENTER

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Nathaniel B. Guttman
National Climatic Data Center
Asheville, NC

Jung Jin Lee
Department of Statistics
SoongSil University
Seoul, Korea

James R. Wallis
IBM Watson Research Center
Yorktown Heights, NY

In December 1992 a period of wetness began in southern Arizona. According to the Weekly Climate Bulletin (Climate Analysis Center, 1992,1993), heavy precipitation inundated parts of Arizona in December; more than 400 percent of normal December precipitation fell in the southwestern part of the State. Heavy precipitation continued to fall during the next two months causing extensive flooding along the Gila River. This article summarizes the flood damage and the probabilities of observing the heavy rainfall.

Monthly storm data reports sent from the Phoenix Weather Service Forecast Office to the National Climatic Data Center indicate flooding along the Santa Cruz and San Pedro Rivers on the 29th of December. From January 7-20, roads, bridges, homes, businesses and farmland suffered considerable flood damage from Graham County westward to Yuma County as rivers and streams swelled. Several thousand people were isolated in their homes as flood waters cut off roads. The January Storm Data Report indicates that the combination of a northward-displaced subtropical jet stream, with its abundant moisture supply and associated low pressure disturbances, and a southward-displaced polar jet stream, with its storm track, led to the abnormally wet period from just after Christmas to mid-January. In February, severe flooding was reported in several areas as water rose in the Painted Rock Reservoir; water accumulating behind the dam produced the largest lake in the state. After exceeding the 2.5 million acre-feet capacity of the reservoir, water began spilling over the dam and damaging homes, crops, farmland, roads, and bridges. About 3,500 residents were evacuated, and the National Guard responded to the flooding with various relief efforts including helicopter support operations.

Press reports and summaries prepared by both the United States and Arizona Departments of Agriculture indicate flood damage in excess of $50 million. In addition to loss of a substantial part of the lettuce crop and the subsequent market volatility (Arizona normally supplies about 70 percent of the country's lettuce in March), there has been extensive damage to agricultural structures, irrigation and pumping systems, and farmland. The effects of the flooding are expected to disrupt agriculture in the area for several months to come.

Given the extensive damage resulting from this extremely wet period, a question arises as to what is the probability of occurrence of rainfall of this magnitude? This question is similar to one which prompted the development of a National Drought Atlas.

Sponsored by the U.S. Army Corps of Engineers, under the direction of Dr. Gene Willeke, Miami (Ohio) University, a National Drought Atlas is being prepared jointly by the National Climatic Data Center, U.S. Geological Survey, and IBM Watson Research Center to give water managers probabilistic information for use in making water-related decisions during periods of drought. Distribution in both paper and electronic form is expected to begin in October 1993. A component of the Atlas is a probability analysis of total precipitation occurring over 1, 2, and 3 months with the durations beginning in each calendar month. Because water managers want to know the probability that reservoirs drawn down during droughts will refill in the next n months, the Atlas also includes the probabilities of extremely wet periods.

The Atlas results were applied to the Phoenix area to estimate the rarity of the monthly precipitation that occurred from December 1992 through February 1993. The probability estimates are presented as an example of available information that could be useful to decision makers who manage water resources during times of stress.

Probability distributions describing 1-, 2-, and 3-month precipitation totals for 111 regions within the contiguous United States were determined from L-moments (Guttman et al, 1993). These moments are linear combinations of order statistics (Hosking, 1990). The L-moment technique depends upon homogeneity within a region. It is assumed that data observed at all locations in a region are random representations of a physical process that is operating everywhere in the region. Weighted, average, regional, dimensionless quantile functions were computed from distributions found to be acceptable by goodness-of-fit tests. Site-specific quantile estimates are obtained by multiplying the site mean (scale factor) by the regional quantile function. Figure 1 shows the 111 regions that resulted from the cluster analysis of 1,119 precipitation sites (Guttman, 1993). Figure 2 is an enlargement of the Arizona portion of Fig. 1 and shows the location of the principal dams in the area, the two Atlas precipitation regions (71 and 72), and the seven sites within the Gila River drainage area that were used in the Atlas precipitation analysis. The primary difference between regions 71 and 72 is that in region 71, average annual precipitation is less than 12 inches, and in region 72, average annual precipitation is more than 12 inches.

The historical precipitation data used to construct the regions and to derive the probabilities were taken from 1,119 of the National Climatic Data Center's 1,219-station Historical Climatological Network (Karl et al., 1990) with monthly data through 1989. Record lengths are at least 60 years and average about 85 years. Other than record length, the criteria for selecting the stations are that no more than ten percent of the monthly data are missing, and that no more than twelve consecutive months of data are missing. Since all available data meeting the selection criteria are used, record lengths are not constant among stations.

Probability estimates of the winter precipitation that occurred at the 7 sites in Arizona were computed from the Atlas information. Observed December 1992, January and February 1993 monthly precipitation amounts for the sites were extracted from preliminary forms sent to the National Climatic Data Center. The winter wetness is assessed relative to the observed record (probabilistic climatology).

Longterm average 1-, 2- and 3-month precipitation totals during the winter months for the 7 sites are shown on Table 1, and the observed amounts from December 1992 through February 1993 are shown on Table 2. Comparing these two tables, it is obvious that rainfall far exceeded the longterm average at each site during each month. Precipitation in January 1993 was particularly excessive. The December-January 2-month totals were more than 3 times the longterm average. The January-February as well as the December-February totals were more than 4 times the longterm average.

Table 3 shows the probability of exceeding the observed totals. The inverse of the listed probabilities is the mean return period of the observed precipitation. Looking at the individual months, the December totals may be expected to occur once every 15 to 20 years at all sites except Buckeye. The December rainfall at this site can be expected to occur once in 125 years. January was even more unusual; 5 out of the 7 sites reported values that yield recurrence intervals more extreme than 1,000 year events. February precipitation was quite variable but less severe than January; the return periods ranged from 14 years at Mesa to 125 years at Wickenburg. The 2-month December-January totals were once in more than 250-year events at all sites except Sacaton and Wickenburg. At Sacaton, the 2-month rainfall could be expected to occur about once every 33 years, while at Wickenburg, the expectation is about once every 90 years. The January-February totals, as well as the 3-month December-February totals, were exceptionally high; they could be expected to occur once in more than a 1,000 years.

Confidence in estimates of return periods of hundreds of years based on sample sizes of fewer than 100 is low. As a guide to estimates that have higher confidence, Tables 4 and 5 show the .95 confidence interval, obtained by simulation, of precipitation that can be expected to occur on the average of once every 50 and 100 years. Intervals for longer return periods are likely to be too broad to be useful except for very general comparisons similar to those in the previous paragraph.

Despite low confidence that can be placed on very small estimated probabilities, the precipitation that fell from December 1992 through February 1993 could be considered to be an extremely rare event. A similar but not as severe an event occurred from January through April 1905 (Weather Bureau, 1905). In the region from Phoenix to Tucson, January precipitation was about 2 inches. February rainfall totals were more than 4 inches at most locations, with Buckeye receiving a record 6.46 inches. During March and April, the monthly totals were generally between 2 and 3 inches. The 1905 event was the most extreme previously recorded event, but it was significantly less intense than in January-February 1993 (and certainly in December 1992-February 1993).

More than half the sites in each of the two regions that were used to compute the regional quantiles included observations from the 1905 event. However, of the seven sites used in the current analysis, only data from Buckeye and Roosevelt include the 1905 precipitation. The possibility therefore exists that the data used are not representative of the historical events at all sites in the two regions. However, even if the 1905 event had been measured at all sites, it is probable that the regional quantiles would have changed little and would still indicate that the 1992-1993 winter precipitation was a very rare occurrence. If it is accepted that the winter precipitation was indeed an extremely rare event, i.e., the observed precipitation could be expected to occur once in more than a few hundred years, then the question could be asked, "What is the effect the probabilistic knowledge could have on water managers' decisions?"

Operationally, water management decisions are generally based on current conditions and on the forecasts issued by the National Weather Service. Taken into consideration are, for example, current streamflows, potential increase in streamflows from snowmelt and/or precipitation, reservoir capacity, dam outflow channel capacity, and projected losses from varying degrees of flooding. Historical probabilities of the occurrence of extreme precipitation are not major factors in making decisions to contain water in reservoirs or to release water into downstream channels.

The historical record is important, however, in planning for extreme events. In the aftermath of the floods, one might ask, "Should we have built larger dams or other structures that would have prevented damage from the winter rains?" Descriptions of prior events, such as the one that occurred in 1905, enhance the background knowledge necessary to minimize damage from unusual events. They also subjectively influence the degree of risk that decision makers are willing to take.

It is a well established principle in water resources planning that the damage from large, but rare, events must be weighed against the higher costs (financial, environmental and social) of larger preventive projects. Structures necessary for the economic well-being of an area, such as roads, bridges, buildings, irrigation systems, drainage facilities, dams, etc., are designed and built to withstand unusual events that are expected to occur with a quantified frequency. The U.S. Army Corps of Engineers, for example, generally recommends project sizes that reasonably maximize the net national economic benefits. The Corps recognizes a residual risk as the consequence of large events times the probability of the events (U.S. Army Corps of Engineers, 1992). In theory, this deterministic approach leads to a rational dam size because one can demonstrate that it is cheaper to pay for damages from large, rare events than to build the more costly project that would prevent the damages.

The information presented herein is intended for decision makers and builders who will be redesigning and reconstructing the facilities that were damaged or destroyed by the Gila River flooding. The historical probabilistic estimates should be used to refine the probability estimates of larger events when assessing plans to build new structures and systems.

REFERENCES

Climate Analysis Center, Weekly Climate Bull., Washington, DC, No. 92/41-93/9, 1992-1993.

Guttman, N.B., The use of L-moments in the determination of regional precipitation climates, J. Climate, in press, 1993.

Guttman, N.B., J.R.M. Hosking and J.R. Wallis, Regional precipitation quantile values for the continental U.S. computed from L-moments, J. Climate, in press, 1993.

Hosking, J.R.M., L-moments: analysis and estimation of distributions using linear combinations of order statistics, J. Royal Statist. Soc. B, 52, 105-124, 1990.

Karl, T.R, C.N. Williams, Jr., F.T. Quinlan and T.A. Boden, United States Historical Climatology Network (HCN) serial temperature and precipitation data, ORNL/CDIAC-30,NPD-019/R1, Carbon Dioxide Information Analysis Center, Oak Ridge Natl. Lab., Oak Ridge, TN, 374 pp., 1990.

U.S. Army Corps of Engineers, Guidelines for risk and uncertainty analysis in water resources planning, volume 1, IWR Report 92-R- 1, Inst. for Water Resources, Ft. Belvoir, VA, 10-12, 1992.

Weather Bureau, Reports from January-April 1905, Arizona Section of the Weather and Crop Service, Phoenix, 8 pp., 1905.

Figure Legends

1. Precipitation regions. Lines radiating from the centroid of a region end at the location of the sites within the region.

2. Enlargement of figure 1 showing study locations, dams, and county boundaries. Superimposed are the centroids of regions 71 and 72 and lines radiating to the locations of region sites (truncated at the enlargement boundary).

Table 1. Longterm average precipitation (inches).

Site	Dec	Jan	Feb	Dec-Jan	Jan-Feb	Dec-Feb
Wickenburg	1.24	1.18	1.07	2.46	2.26	3.52
Buckeye	0.87	0.81	0.71	1.70	1.53	2.43
Mesa	1.06	0.85	0.79	1.92	1.64	2.72
Sacaton	1.08	0.84	0.78	1.93	1.63	2.71
Childs	2.11	1.89	1.71	4.01	3.62	5.77
Roosevelt	2.00	1.87	1.79	3.84	3.66	5.57
Miami	2.30	2.08	1.76	4.41	3.84	6.17

Table 2. Observed precipitation (inches).

Site	Dec	Jan	Feb	Dec-Jan	Jan-Feb	Dec-Feb
Wickenburg	3.46	5.34	5.20	8.80	0.54	14.00
Buckeye	4.52	4.30	2.70	8.82	7.00	11.52
Mesa	3.18	5.81	2.19	8.99	8.00	11.18
Sacaton	3.28	2.29	1.59	5.57	3.88	7.16
Childs	5.97	9.77	4.80	15.74	14.57	20.54
Roosevelt	5.80	11.25	5.21	17.05	16.46	22.26
Miami	6.43	10.29	5.98	16.72	16.27	22.70

Table 3. Exceedance probabilities.

Site	Dec	Jan	Feb	Dec-Jan	Jan-Feb	Dec-Feb
Wickenburg	.076	.001	.008	.011	< .001	.002
Buckeye	.008	< .001	.022	.001	< .001	< .001
Mesa	.061	< .001	.073	.002	< .001	.002
Sacaton	.059	.023	.154	.030	.050	.079
Childs	.052	< .001	.036	.003	.001	< .001
Roosevelt	.048	< .001	.033	.001	< .001	< .001
Miami	.054	< .001	.020	.004	< .001	< .001

Table 4. Precipitation range (.95 confidence) for 50-year return period.

Site	Dec	Jan	Feb	Dec-Jan	Jan-Feb	Dec-Feb
Wickenburg	4.21	3.40	3.43	6.95	4.85	8.83
	5.22	4.22	4.30	8.47	7.07	10.65
Buckeye	2.95	2.34	2.28	4.81	3.97	6.10
	3.66	2.90	2.86	5.87	4.80	7.36
Mesa	3.59	2.43	2.53	5.42	4.24	6.82
	4.45	3.01	3.18	6.61	5.12	8.24
Sacaton	3.65	2.42	2.48	5.46	4.20	6.81
	4.52	3.01	3.12	6.66	5.09	8.22
Childs	6.49	5.35	4.72	10.47	8.72	13.17
	8.42	6.91	6.28	12.58	10.38	15.44
Roosevelt	6.14	5.31	4.94	10.03	8.81	12.71
	7.97	6.85	6.57	12.05	10.49	14.90
Miami	7.08	5.92	4.86	11.51	9.25	14.07
	9.19	7.63	6.46	13.83	11.01	16.50

Table 5. Precipitation range (.95 confidence) for 100-year return period.

Site	Dec	Jan	Feb	Dec-Jan	Jan-Feb	Dec-Feb
Wickenburg	4.87	3.69	3.82	7.87	6.44	9.88
	6.21	4.79	5.11	9.87	8.18	12.22
Buckeye	3.41	2.53	2.54	5.45	4.38	6.83
	4.35	3.29	3.39	6.83	5.55	8.44
Mesa	4.15	2.63	2.82	6.14	4.67	7.64
	5.30	3.42	3.77	7.70	5.93	9.45
Sacaton	4.42	2.63	2.76	6.18	4.64	7.62
	5.39	3.42	3.70	7.76	5.88	9.42
Childs	7.28	5.94	5.21	11.74	9.63	14.16
	10.23	8.22	7.86	14.51	11.77	17.22
Roosevelt	6.89	5.90	5.45	11.25	9.74	13.67
	9.68	8.16	8.22	13.90	11.90	16.62
Miami	7.95	6.57	5.36	12.91	10.22	15.13
	11.16	9.08	8.08	15.96	12.49	18.40

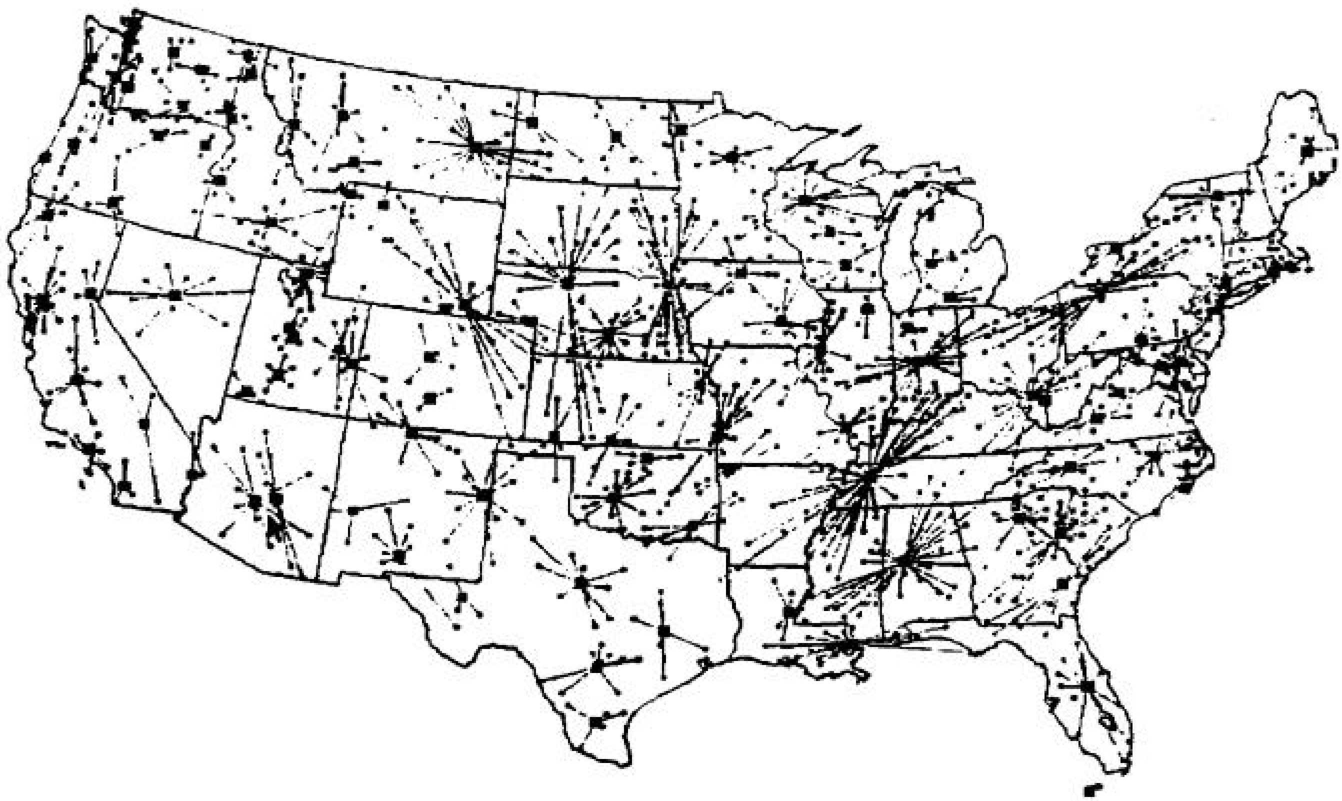

Figure 1

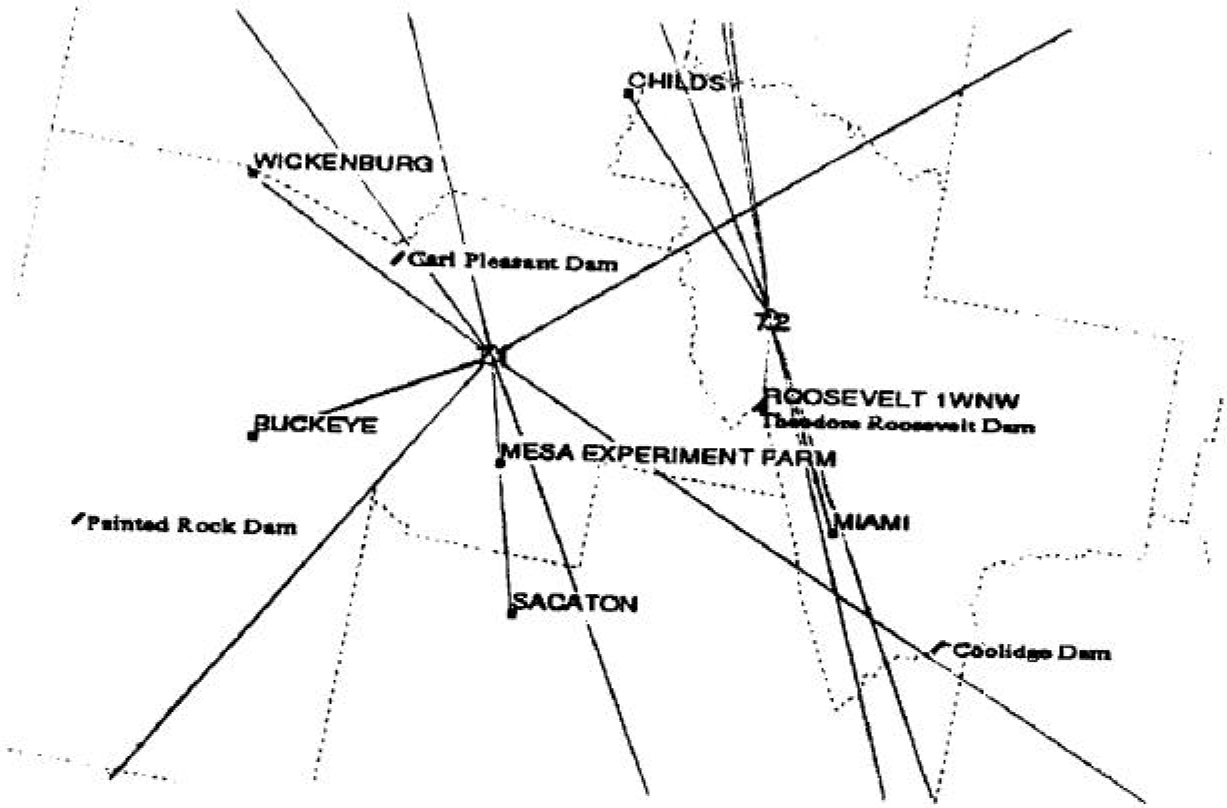
CHILDS
WICKENBURG
Carl Pleasant Dam
ROOSEVELT 1WNW
Theodore Roosevelt Dam
BUCKEYE
MESA EXPERIMENT FARM
Painted Rock Dam
MIAMI
SACATON
Coolidge Dam

Figure 2